BLIND PARAMETER ESTIMATION BASED MATCHED FILTER DETECTION FOR COGNITIVE RADIO NETWORKS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Electronics and Communication Engineering
Specialisation**: Communication and Networks**
By

Shatrunjay Upadhyay
(Roll: 213EC5253)

Department of Electronics and Communication
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Rourkela-769 008, Odisha, India
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Under the supervision of

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CERTIFICATE

This is to certify that the work in the thesis entitled, "**Blind Parameter Estimation Based Matched Filter Detection for Cognitive Radio Networks"** submitted by **Mr. ShatrunjayUpadhyay** in partial fulfilment of the requirements for the award of **Master of Technology Degree** in the Department of Electronics and Communication under the specialisation of Communication and Networks, National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the work reported in this thesis is original and has not been submitted to any other Institution or University for the award of any degree or diploma.

He bears a good moral character to the best of my knowledge and belief.

Place: NIT Rourkela
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Declaration

I certify that

a) The work contained in the thesis is original and has been done by myself under the general supervision of my supervisor.

b) The work has not been submitted to any other Institute for any degree or diploma.

c) I have followed the guidelines provided by the Institute in writing the thesis.

d) Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.

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Shatrunjay Upadhyay

25th May 2015

ACKNOWLEDGEMENT

For each and every new activity in the world, the human being needs to learn or observe from somewhere else. The capacity of learning is the gift of GOD. To increase the capacity of learning and gaining the knowledge is the gift of GURU or Mentor. That is why we chanted in Sanskrit "*Guru Brahma Guru Bishnu Guru Devo Maheswara, Guru Sakshat Param Brahma Tashmey Shree Guruve Namoh*". That means the Guru or Mentor is the path of your destination.

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Shatrunjay Upadhyay

Abstract

Recent advancements in wireless communication applications have generated the need for very large spectrum. The assignment of a frequency spectrum permanently to a particular user has led to underutilization of available spectrum.The solution to more spectrum demand lies in offering licensed idle spectrum to other non-licensed requesting user temporarily. Cognitive Radio is an environment aware, intelligent system that exploits the spectrum holes and enhances the usage of limited frequency spectrum resource so that more user can be accommodated in limited band. In order to detect spectrum holes in wideband spectrum many techniques have been proposed for spectrum sensing out of which Energy detection (ED), Cyclostationary (CS) detection and Matched Filter (MF) detection are most discussed and most practiced .Energy detection (ED) technique is a vastly used sensing technique in CRNs because of its operational simplicity. However at low SNR, the performance of ED is badly degraded. Matched Filter (MF) detection is an alternate sensing technique at low SNR, as it increases SNR of the received signal. MF detector gives far better performance when compared to ED at low SNR. But the problem with MF detector is that it must have priori knowledge about Primary User (PU) signal, therefore we need dedicated MF detector for each PU.

Motivated by above drawback of ED and MF a new MF technique is proposed by which requirement of priori information of PU signal can be eliminated. At the MF detector front end, we perform blind estimation of PU signal parameters and accordingly update the coefficient of MF transfer function. Blind Estimation of signal parameters solves the problem of having priori information about PU signal for MF detector.

Content

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NOMENCLATURE

Δt	:	Total observation interval
T	:	Sliding window interval
N	:	Number of samples in the observation interval Δt
N_p	:	Number of samples in sliding window T
f_s	:	Sampling frequency
T_s	:	Sampling Period
f	:	Spectral frequency
Δf	:	Spectral frequency resolution
$\Delta\alpha$	:	Cyclic frequency resolution
$S_x^\alpha(f)$	:	SCD function
P_{fa}	:	Probability of false alarm
P_d	:	Probability of detection
K_f	:	Frequency sensitivity of the FM modulator
$I_0(u)$	:	Modified Bessel function of 1^{st} kind and order zero
Δf	:	Frequency deviation

α	:	Cyclic frequency
$R_x^\alpha(\tau)$	:	Cyclic autocorrelation function of $x(t)$
$X_T(n, f)$	:	Complex demodulate of $x(t)$ over interval T
λ	:	Threshold
σ_w^2	:	Variance of the noise signal
σ_s^2		Variance of the primary user signal

ABBREVIATIONS

A/D	:	Analog-to-Digital converter
AM	:	Analog Modulation
AWGN	:	Additive White Gaussian Noise
CAF	:	Cyclic auto-correlation function
CDP	:	Cyclic Domain Profile
CR	:	Cognitive Radio
CS	:	Cyclostationary
ED	:	Energy Detection
FAM	:	FFT Accumulation Method
FCC	:	Federal Communication Commission
FFT	:	Fast Fourier Transform
FM	:	Frequency Modulation
FS	:	Frequency Smoothing
GSM	:	Global System for Mobile
IEEE	:	Institute of Electrical and Electronics Engineers
LO	:	Local Oscillator
MAC	:	Media Access Control
MF	:	Matched Filter

NLOS	:	Non- Line-of-Sight
pdf	:	Probability density function
PHY	:	Physical
PSD	:	Power Spectral Density
PU	:	Primary User
RF	:	Radio Frequency
ROC	:	Receiver Operating Characteristics
SCD	:	Spectral Correlation Density
SCF	:	Spectral Correlation Function
SNR	:	Signal-to-Noise Ratio
SSCA	:	Strip Spectral Correlation Algorithm
TS	:	Time Smoothing
UHF	:	Ultra High Frequency
VHF	:	Very High Frequency

CHAPTER 1

1. INTRODUCTION

1.1. BACKGROUND

Wireless applications have made the life simpler and easier in many aspects. There is ready to use connection, no incur of maintenance cost for connection, no physical space required for connecting media so no protection for connecting media needed. Last decade have witnessed the invention of a large range of wireless based applications and equipment. With the advent of 3G and upper generation technologies the demand of spectrum has been increased by more than thousand fold [1]. Limitation of operation of wireless equipment over restricted range of frequency makes spectrum limited and valuable resource. This valuable and limited Spectrum is catalyst to economic development of a country and has been a basic need of its people. So it should be used intelligently and efficiently. The current state-of-the-art wireless apparatuses usually works in unlicensed frequency band i.e. 2.4 GHz ISM band and 900 MHz band. Which is rendering these frequency band more congested day by day? While the other licensed spectrums such as 400-700 MHz remain unutilized or occasionally utilized.

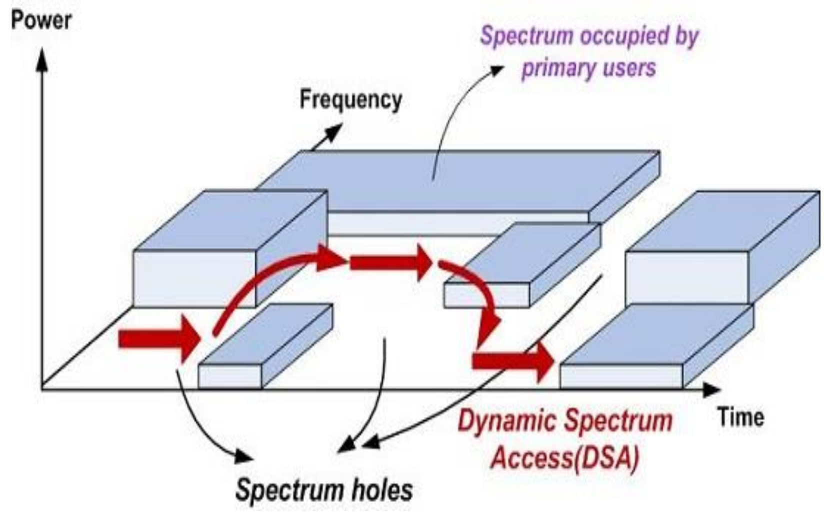


Fig. 1.1 Spectrum Hole Concept

Surveys have shown that 60 percent of licensed spectrum below 6 GHz is being underutilized [2] as shown in Fig.1. The solution to more spectrum demand lies in offering licensed idle spectrum which is also a.k.a. white spectrum or spectrum hole to other non-licensed requesting user (Secondary User) temporarily. Cognitive Radio (CR) makes spectrum usage more efficient by detecting spectrum holes and dynamically assigning these spectrums to unlicensed users or secondary users as shown in Fig.2. CR is an environment aware, intelligent system that exploits the spectrum holes and enhances the usage of limited frequency spectrum resource so that more user can be accommodated in limited band [3]. In order to detect spectrum holes in wideband spectrum many techniques have been proposed for spectrum sensing out ofwhich Energy detection (ED), Cyclostationary (CS) detectionand Matched Filter (MF) detection are most discussed and most practiced [3] [4].

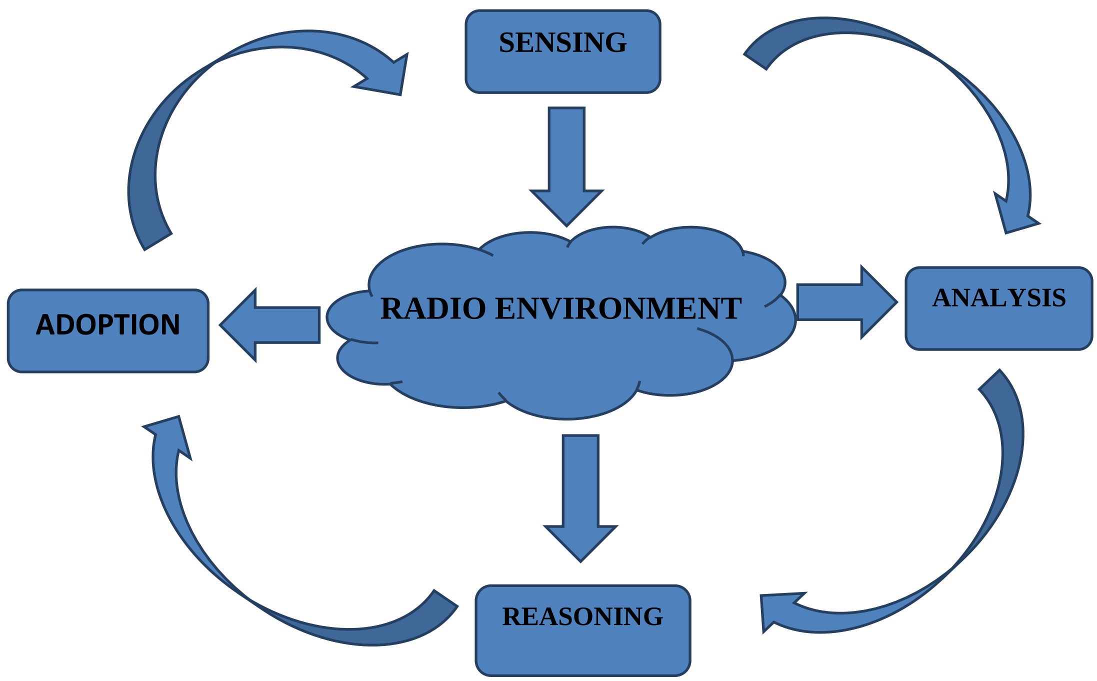


Fig.1.2 Cognitive Radio Networks

CR network always sense, track and analyse its environment to use the available spectrum at optimum level. For efficient performance of a CR network it should have following features-

1. **Frequency Agility**

   CR network should be very quick in changing frequency to avoid interference for PU and uninterrupted communication of SU.

2. **Adaptive Modulation**

   CR should be able to reconfigure its transmission parameters like data rate, modulation technique to exploit the available spectrum hole at maximum.

3. **Transmission Power Control**

   For maximum sharing of spectrum the transmission power should be kept at minimum level while it should be at maximum limit when needed.

4. **Able to Sense The Environment**

   For detection of available spectrum holes the CR should be able to sense the RF environment around it along with the tracking of its internal operating parameter.

5. **Sharing Information with Neighbouring Nodes**

   Sharing the information with neighbouring nodes and passing decision to them makes CR network more reliable and efficient

1.2. LITERATURE SURVEY

Paper [1] [2] [3] discusses the practical issues for deployment of spectrum management systems with cognitive radios, with its ability to be both intelligent and frequency agile, a solution to provide the necessary capabilities needed for dynamic spectrum access. The technique for fine and precise spectrum sensing to control interference by out of band radiation is suggested in paper [4]. Paper [5][6][7][10] suggest the techniques for wideband spectrum sensing. Main techniques includes transmitter detection, interference based detection and cooperative detection and many techniques under these scheme with their issues and challenges are discussed in detail. And also compare their performance in different environment. Paper [8][9] describes the most used spectrum sensing technique i.e. ED with merit, demerit, challenges and limitation of this technique. A robust technique named as Cyclostationary feature based detection for sensing spectrum hole is described in dissertation in [11] and [12]. The authors have given the method with formulation and performance proof of said technique. The major work for this project work is done referencing [13] and [14] which have discuss the method of MF detection in detail with formulation, probability of detection, false alarm etc. In papers [16][17] authors suggests proposed the way to estimate signal parameter at receiver front without knowing any data from transmitter side. Which have been used as remedy for problem of having prior information for CR user in CR network. Reference [18] have given well proved algorithm which is used for refinement of coarse symbol rate in least square estimator.

1.3. MOTIVATION

Recent advancements in wireless communication applications have generated the need for very large spectrum. The policy of licensing a spectrum to a particular user on permanent basis have turn into fiasco. In permanent allocation of spectrum, large part of the licensed spectrum is not used all the time or remain idle at all. To use the available spectrum at its full, idle spectrum or spectrum holes can be accessed dynamically and can be allocated to the requesting user temporarily until licensed user does not require its frequency band for communication. The stated principle is used in Cognitive Radio Ad-hoc Networks.

To detect the spectrum holes many sensing techniques have been suggested. The mainly used sensing techniques are 1. Energy Detection 2. Matched Filter Detection 3. Cyclostationary Detection. Energy detection technique is the simplest of all. It is a non-coherent detection technique, only requires to calculate energy of the received signal. Calculated energy of received signal is compared with predetermined threshold to detect the existence of primary user signal in the channel. But this technique is not much loyal for low signal to noise ratio. Another technique is Cyclostationary detection technique. In this technique the spectral correlation density is used as test statistic and compared with the threshold to determine the existence of PU signal. But the drawback of this technique is that, it is very much complex as large computation is required [5] [6]. Next sensing technique is MF detection that performs best in the Additive White Gaussian Noise (AWGN) environment. In this technique shape of the transmitted signal is known that determines the MF transfer function. MF output is the correlation between received signal and transfer function of MF. The response of MF is compared with a predetermined threshold to decide whether signal is present or absent. Its performance lies between that of ED and CS detector [6] [7]. In addition, MF detection yields far better performance than ED in terms of PU signal detection at lower SNR. But the challenge encountered with MF detection is detector should have priori information about modulation type, pilot carrier of the transmitted signal. This implies dedicated MF detector is required to sense each PU signal.

From above discussion we can say that the MF detection is more faithful than ED at low SNR and less complex than CS detection scheme. The main motive behind this project work is to leverage the pros and counter the main problem of MF detection i.e. requirement of prior information about the PU signal.

1.4. OBJECTIVE OF WORK

The main objective of this project work to eliminate the problem of having information such as modulation type, carrier frequency and bit rate of PU signal for MF detection. In conventional MF detection we have the full information of the PU signal and the transfer function of MF is updated accordingly. In proposed MF detection, we blindly estimate the parameters of the PU signal. Estimating the signal parameters, the coefficients (transfer function) of MF is updated. Received signal is matched by MF and test statistic for the proposed MF detection is fixed. This test statistic is compared with the predetermined threshold to decide the presence or absence of the signal in the channel. The blind estimation of signal parameter is done by performing Inverse Fourier Transform

(IFFT) of the received signal. By processing and analysing the IIFT of power spectrum of received signal, different parameters of signal is calculated. Blind estimation in this project work is performed in three phases. 1. Pre-processing of the received signal 2. Calculating roll-off factor and coarse estimation of symbol rate 3. Calculating refined symbol rate. Requirement and method of these steps are discussed in fourth chapter of this thesis in detail.

1.5. THESIS ORGANISATION

This thesis is organised in five chapters. Current chapter, first chapter presents the background, requirement and introduction of CRAHNs in first section. Then literature survey, motivation behind project work, purpose and thesis organisation is presented in subsequent sections respectively.

Backbone of CRAHNS, spectrum sensing techniques are described in **Chapter 2. Chapter 2** also contains comparison of Main spectrum sensing techniques, their pros and cons and ends with explanation of different kind of probabilities which are essential for taking decision of existence of PU signal in the channel.

Chapter 3 is dedicated to description of blind estimation of signal parameter.

Proposed MF detection using blind estimation of signal parameter is explained in **chapter 4**. Which contains block diagram, simulation results and discussion of proposed technique.

Finally this dissertation ends with conclusion and future scope of the accomplished project work with **Chapter 5.**

CHAPTER 2

2. SPECTRUM SENSING TECHNIQUES

Spectrum sensing is the main operation in a CR network at which the complete performance of CR lie upon. Spectrum hole should be detected precisely for the use of SU and to avoid interference to PU signal caused by SU signal. Due to these conditions spectrum sensing plays a critical role in CR networks. Spectrum sensing performs the measurement, sensing and tracking of channel parameters, noise, and interference, transmit power, availability of spectrum and radio operating environment. Spectrum sensing can be performed across time, frequency, phase, geographical space and code.

In CR networks the unlicensed user (secondary user) needs to monitor the activity of licensed user (primary user) continuously in order to find the spectrum hole which are nothing but frequency band which can be used by SU temporarily without interfering with PU. The above explained procedure is known as Spectrum Sensing.

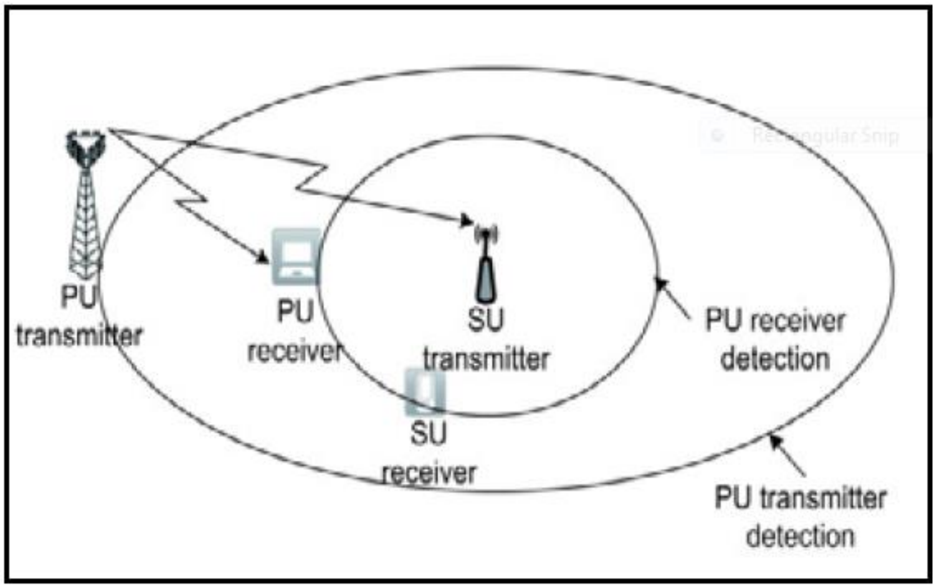


Fig.2.1. Principle of spectrum sensing

There are two types of spectrum holes 1. Temporal spectrum hole 2. Spatial spectrum hole respectively

1. Temporal spectrum holes are those frequency bands which are not being used by licensed users for a period of time and can be used by SU in that period.

2. Spatial spectrum holes are those frequency bands which are being used within a geographical area by PU and can be used by SU outside that area.

Many spectrum sensing techniques have been suggested to detect the spectrum holes. Some most used techniques are Energy detection, Matched Filter detection, Cyclostationary detection, wavelet based detection etc. The performance of spectrum sensing techniques is limited by wireless channel’s fundamental characteristics as multipath fading, shadowing and noise uncertainty of the channel. Spectrum sensing techniques can be classified as below-

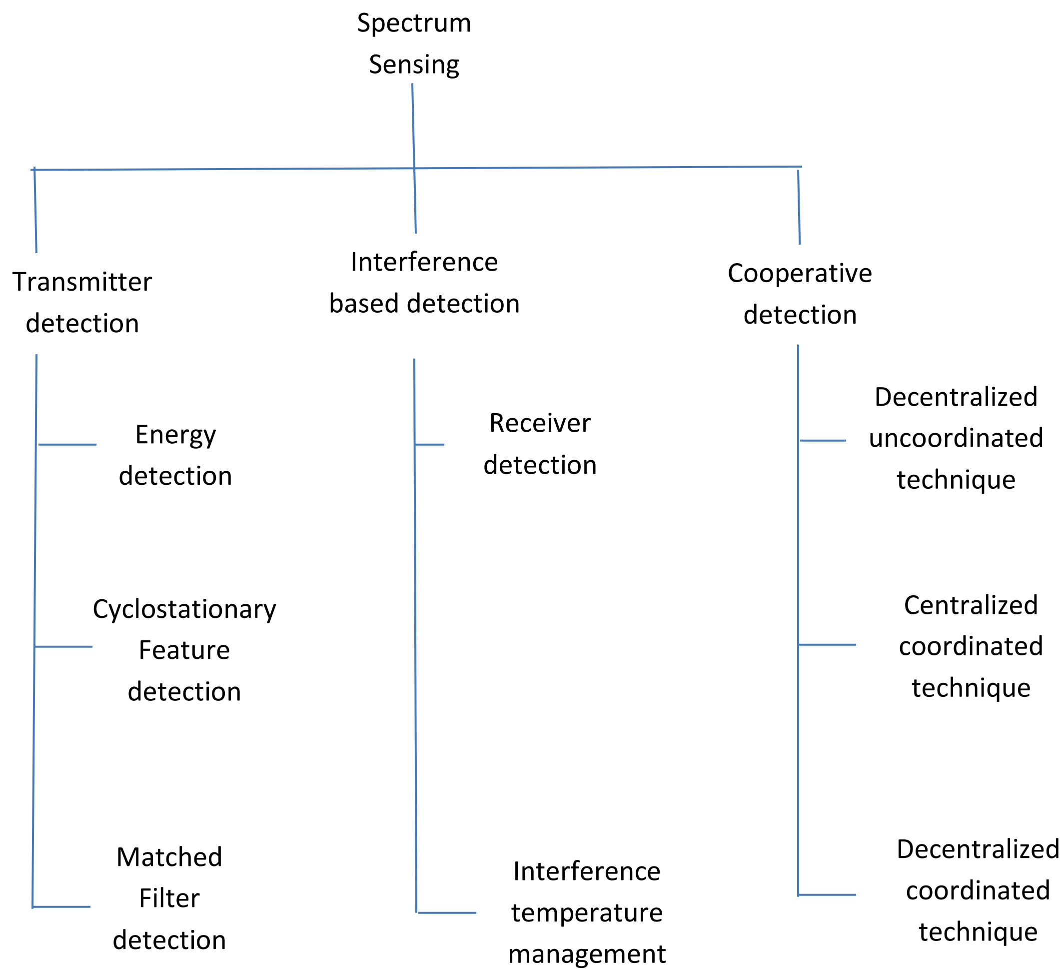


Fig.2.2. Classification of spectrum sensing techniques

2.1. TRANSMITTER DETECTION

It is most widely used spectrum sensing technique for the detection of spectrum holes in CR environment. SU has to scan its surrounding RF environment to find out the existence of PU signal. Since SU has no prior knowledge of PU signal, there is always a chance of false detection of PU signal as noise. Transmitter detection is performed by various signals processing techniques of which three most popular technique are 1. Energy detection technique, 2. Cyclostationary feature detection technique and 3. Matched Filter detection technique respectively. These techniques are explained in detail in forthcoming sections.

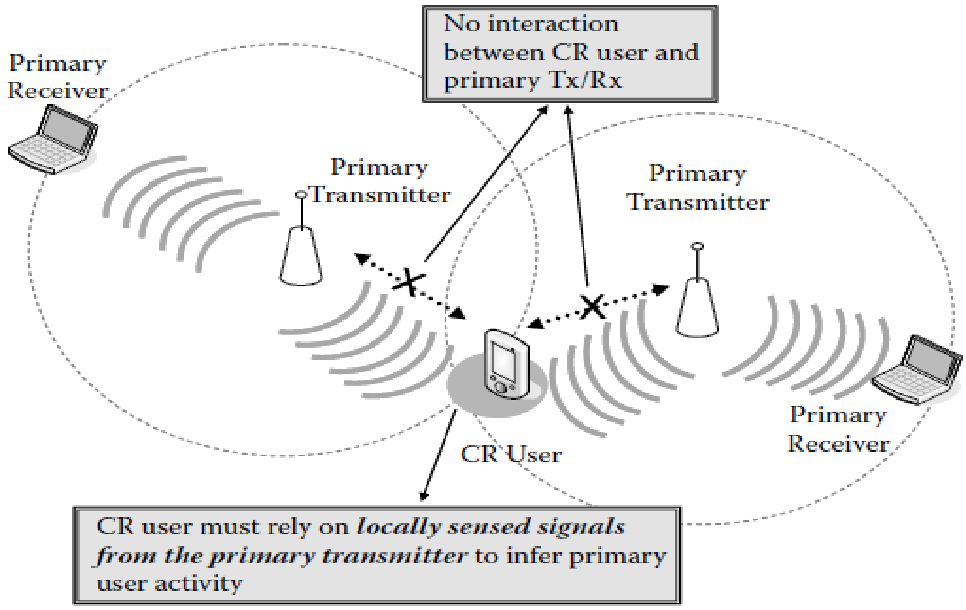


Fig.2.3. Transmitter Detection

2.1.A. ENERGY DETECTION

It is a non-coherent, sub-optimal detection technique. It is the most used spectrum sensing technique due to its simple implementation and short sensing time. For sensing of PU signal this technique doesn't need any prior information about PU signal. Energy detection can be performed in both time domain as well as in frequency domain.In time domain detection for a specific frequency band, A band pass filter (BPF) is applied to select the required frequency band and power is calculated from each sample in the band for observed period. Energy detection in frequency domain is done by converting time domain signal in frequency domain by performing FFT over time domain signal. And signal power is calculated by summing the power of all frequency components.

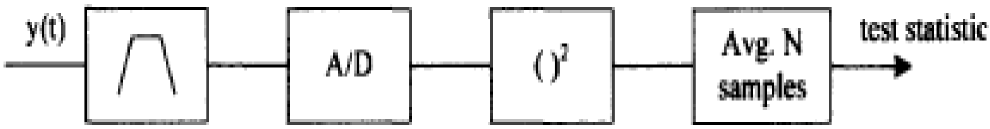


Fig.2.4. Energy detection in time domain

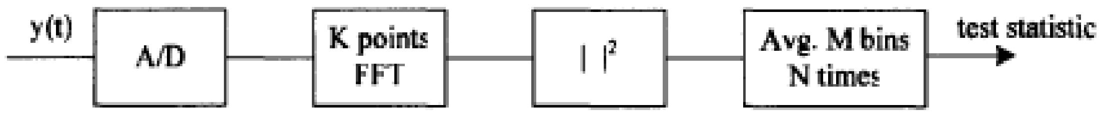


Fig.2.5. Energy detection in frequency domain

In this technique, the energy of the received signal is computed and compared against threshold to determine the existence of PU signal. Threshold in this case depend only upon input signal power and Gaussian noise power. For determination of energy of the received signal, the samples are squared and integrated over the observation interval and the output of the integrator is then compared with the calculated threshold. If the output of the integrator exceeds the threshold then it is assumed that the given radio spectrum is occupied otherwise it is treated as vacant. It can be explained by flow diagram at next page.

Decision for presence or absence of PU signal is taken based on binary hypothesis model. The binary hypothesis test model for taking decision is given as

$$r_x[n] = \begin{cases} w[n] & ;H0\ Hypothesis \\ p[n] + w[n] & ;H1\ Hypothesis \end{cases} \tag{2.1.A.1}$$

Where $r_x[n]$ is received signal, $H0$ is null hypothesis that signifies no PU signal is present at detector. $H1$ is alternative hypothesis which portrays the presence of noise affected PU signal at the detector.

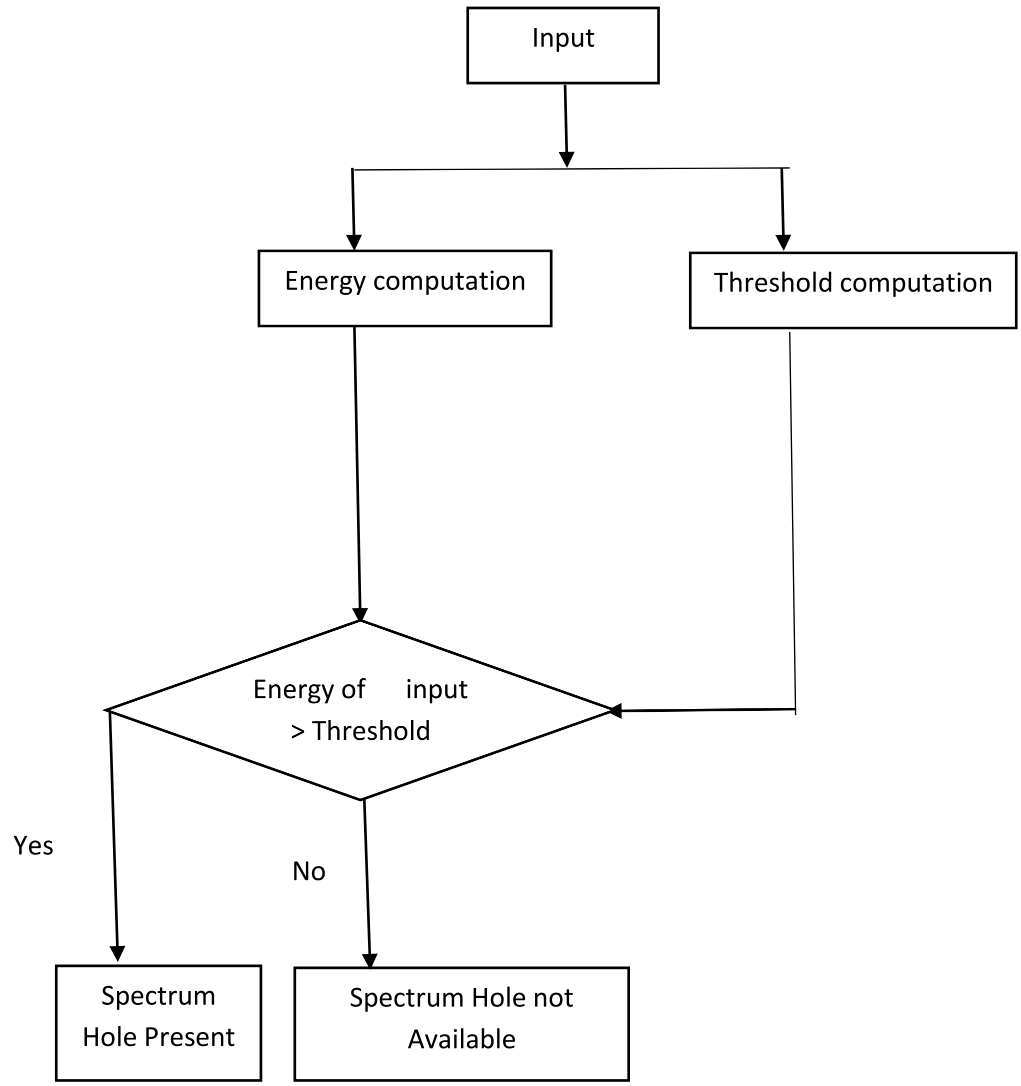


Fig.2.6. Flow diagram of Energy Detection Technique

The PU signal detector has to choose between these two hypothesis on the basis of decision statistic or test statistic. The decision statistic is given as,

$$D_E(r_x) = \sum_{n=0}^{M-1} |r_x[n]|^2 \qquad (2.1.A.2)$$

The decision statistic $D_E(r_x)$ under H0 hypothesis can be considered as a random variable with the probability density function $P_o(D)$ which is a Chi-Square distribution with M degrees of freedom for real case and 2M degrees of freedom for complex case. The binary hypothesis for decision statistic can be modelled as

$$\widehat{r_x} = \begin{cases} H0 & ;\ D(r_x) \leq \Upsilon \\ H1 & ;\ D(r_x) \geq \Upsilon \end{cases} \tag{2.1.A.3}$$

Where Υ is predefined noise dependent threshold. In ED the decision of presence of PU signal is inferred on the basis of energy, which may result into three cases. First case is of correct detection when H1 is decided while H1 is true. Second case is of false alarm when H1 is decided while H0 hypothesis is true and last case is case of miss detection when H0 is decided while H1 hypothesis is true. The probability of occurrence of case 1 is called probability of detection and given as,

$$P_{d,ED} = P(D_{ED} > \Upsilon | H1) \ = Q\left(\frac{\Upsilon - M(\sigma_w{}^2 + \varepsilon_r)}{\sqrt{2M(\sigma_w{}^2 + \varepsilon_r)^2}}\right) \tag{2.1.A.4}$$

Energy of received signal $(\varepsilon_r) = \sum_{n=0}^{M-1} |r_x[n]|^2$ (2.1.A.5)

Probability of decision as case 2 is called probability of false alarm and given by

$$P_{fa,ED} = P(D_{ED} > \Upsilon | H0) \ = Q\left(\frac{\Upsilon - M(\sigma_w{}^2)}{\sqrt{2M(\sigma_w{}^2)^2}}\right) \tag{2.1.A.6}$$

Probability of decision taken as case 3 is called probability of miss detection given as

$$P_{md,ED} = P(D_{ED} < \Upsilon | H1) \ = 1 - Q\left(\frac{\Upsilon - M(\sigma_w{}^2 + \varepsilon_r)}{\sqrt{2M(\sigma_w{}^2 + \varepsilon_r)^2}}\right)$$

$$= 1 - P_{d,ED} \tag{2.1.A.7}$$

Q(.) is complementary distribution function given as

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty \exp(-\frac{y^2}{2})\, dy \qquad (2.1.A.8)$$

Pros and Cons of Energy Detection Technique

It is a non-coherent detection scheme so it have no requirement of prior information of PU signal. It is least complex and fast detection technique.

Main disadvantage of ED technique is that it does not perform well at low SNR. Since its operation is mainly based on energy of input signal it can recognise noise as signal if noise power is more.

2.1.B. CYCLOSTATIONARY FEATURE DETECTION

In this technique, CR user uses the periodic feature of the modulated signal in order to discriminate the PU signal from the noise. It is a complex method among the three techniques. It takes the advantage of the cyclostationary property to distinguish between the PU signal and noise. Generally, the modulated signals exhibit the cyclostationary property due to sampling, cyclic prefix, sine wave carriers, etc. The noise signal doesn't exhibit cyclostationary property since it is a wide sense stationary signal with no correlation among its samples. A signal is said to be cyclostationary if its autocorrelation function is periodic in time. The cyclic autocorrelation function is used for discriminating the signal from noise, which can be described as

$$R_x^\alpha(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} x\left(t + \frac{\tau}{2}\right) x(t - \frac{\tau}{2}) e^{-i2\pi\alpha t} dt \qquad (2.1.B.1)$$

Whereα is cyclic frequency. Fourier transform of CAF gives Spectral correlation density (SCD) function. The SCD is given as

$$S_x^{\alpha}(f) = \int_{-\infty}^{\infty} R_x^{\alpha}(\tau) e^{-2\pi f \tau} d\tau \tag{2.1.B.2}$$

The cyclostationary feature detection is done by correlating the spectral components of the received signal. The decision statistic is derived from SCD function. The detection problem can be represented as

$$\begin{cases} H_0, \text{ if } T(S_x^{\alpha}(f)) \leq \lambda \\ H_1, \text{ otherwise} \end{cases} \tag{2.1.B.3}$$

whereλ is the threshold and $T(S_x^{\alpha}(f))$ is test statistic which is a function of SCD.

Cyclostationary based feature based detection implementation can be shown by Fig 2.6.

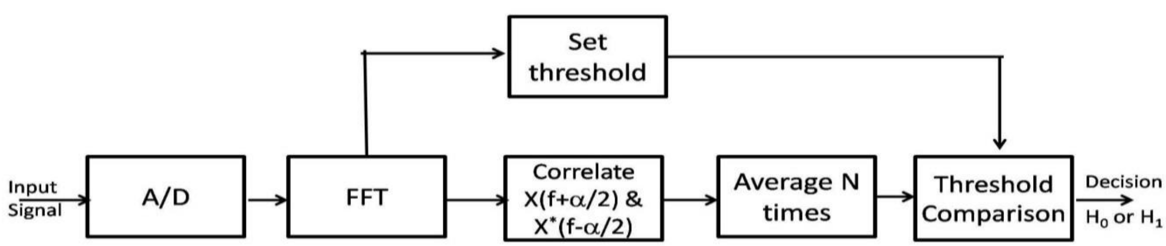


Fig 2.7. Cyclostationary Detection Method

It performs better than the energy detection scheme in low SNR condition. The cyclostationary property is also capable of differentiating signal on the basis of its type. Its main drawback is its large computationally complexity and longer observation interval. It cannot utilize the short duration spectrum holes effectively.

Advantages and Disadvantages of Cyclostationary Feature Detection

It is most reliable detection technique among above discussed classical detection techniques. Its performance does not suffer even at low SNR and high interference.

The disadvantage of this technique is that it is very complex to implement and takes more time more time compared to other two in sensing due to computation of second order statistics.

2.1.C. MATCHED FILTER DETECTION

It is a signal specific detection technique and it maximizes the SNR of the received signal in the presence of AWGN environment. It is an optimal detector where a priori information is available. In this CR user requires some *a* priori information like modulation type, pilot carriers, etc. regarding the PU. Matched filter performs correlation between unknown signals with the known signal. The output of the MF is then compared against the threshold to decide the presence or absence of PU signal in the specified band.

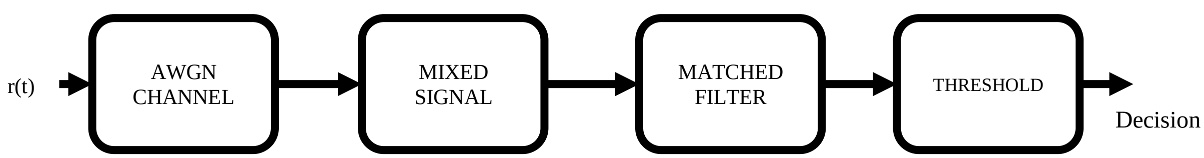


Fig.2.8. Matched Filter Detection Technique

Application of MF at the receiver front end maximizes the SNR. The coefficients of MF are complex conjugate of reversed signal. In MF operation the correlation of known signal p[n] with MF coefficients can be viewed as filtering operation.

If h[n] is the impulse response of the MF, output of the MF can be given as-

$$Y_{MF}[n] = \sum_{k=0}^{M=1} h[n-k] r_x[n] \quad (2.1.C.1)$$

h[n] is the complex conjugate flipped around version of the PU signal given as

$$h[n] = p_s{}^*[M-1-n] \quad (2.1.C.2)$$

From (7) and (8) output of the MF can be given as

$$y_{MF}[M-1] = \sum_{n=0}^{M-1} r_x[n] p_s{}^*[n] = r_x{}^T p_s \quad (2.1.C.3)$$

The decision statistic of MF as shown in [13] is given as,

$$D_{MF}(r_x) = \left| \sqrt{\frac{2}{M \varepsilon_r \sigma_w{}^2}} \sum_{n=0}^{M-1} r_x[n] p_s{}^*[n] \right|^2 \quad (2.1.C.4)$$

Now the binary hypothesis test model can be given as-

$$r_x = \begin{cases} H0 & D_{MF} \leq \Upsilon \\ H1 & D_{MF} \geq \Upsilon \end{cases} \quad (2.1.C.5)$$

Where threshold value Υ is given by-

$$\Upsilon = \frac{\varepsilon_r}{\sigma_w{}^2} \quad (2.1.C.6)$$

False Alarm for the MF detection will be when H1 is decided while H0 hypothesis is true. In this case the received signal $r_x[n]$ at detector front will be noise w[n]. Therefore the output of MF from (9) can be written as-

$$y_{MF}[M-1] = \sum_{n=0}^{M-1} \mathrm{w}[n] p_s{}^*[n] \quad (2.1.C.7)$$

Probability of false alarm for MF detection is given as

$$P_{fa,MF} = P(D_{MF} > \Upsilon | H0) \quad (2.1.C.8)$$

$$P_{fa,MF} = Q\left(\frac{\Upsilon}{\sqrt{\varepsilon_r \sigma_w{}^2}}\right) \quad (2.1.C.9)$$

Probability of detection of PU signal is deciding H1 when H1 hypothesis true. In this case received signal $r_x[n]$ will be $p[n] + w[n]$ and the output MF-

$$y_{MF}[M-1] = \sum_{n=0}^{M-1} \big[p[n] + w[n]\big] p_s{}^*[n] \qquad (2.1.C.10)$$

The probability of detection for MF is given as

$$P_{D,MF} = P(D_{MF} > \Upsilon | H1)$$

$$P_{D,MF} = Q\left(\frac{\Upsilon - \varepsilon_r}{\sqrt{\varepsilon_r \sigma_w{}^2}}\right) = Q\left(\frac{\Upsilon}{\sqrt{\varepsilon_r \sigma_w{}^2}} - \sqrt{\frac{\varepsilon_r}{\sigma_w{}^2}}\right)$$

$$= Q\left(Q^{-1}\big(P_{fa,MF}\big) - \sqrt{\frac{\varepsilon_r}{\sigma_w{}^2}}\right) \qquad (2.1.C.11)$$

Probability of miss detection is deciding H0 while H1 hypothesis is true and is given as-

$$P_{md,MF} = P(D_{MF} < \Upsilon | H1) = 1 - P_{d,MF} \qquad (2.1.C.12)$$

Advantages And Disadvantages Of Matched Filter Detection

This detection technique is optimum detection technique when the prior information of PU signal is known to detector. It is fast detection technique

The requirement of prior knowledge about PU is its biggest disadvantage. In CR network a dedicated MF detector is needed for each type of user.

2.2. INTERFERENCE BASED DETECTION

2.2.A. RECEIVER DETECTION

Receiver detection is similar to transmitter detection technique except in this detection scheme receiver is monitored instead of transmitter to investigate the occupancy of channel. In general the receiver of a communication system emits local oscillator leakage power from its RF front-end while receiving the data. A low cast sensor is installed close to PU's receiver to detect the emitted leakage power by receiver which can confirm the presence of PU signal.

2.2.B. INTERFERENCE TEMPERATURE MANAGEMENT

In this spectrum sensing technique SU allowed to coexist and use the spectrum simultaneously with PU provided it has to regulate its transmission power in order to control harmful interference for PU. An upper limit of interference is set for a frequency spectrum in a geographical area such that the CR user cannot produce harmful interference while using that band in the same geographical location. SUs have to regulate their transmission power i.e. their out of bound emission according to their position with PU in order to control the interference for PUs. The main advantage of this technique is that CR users have not to perform sensing because they are always allow to use the spectrum with a pre-set upper level of power. But this very reason is main disadvantage of this technique because SU have to transmit its data with pre-set upper level of power even if spectrum is idle.

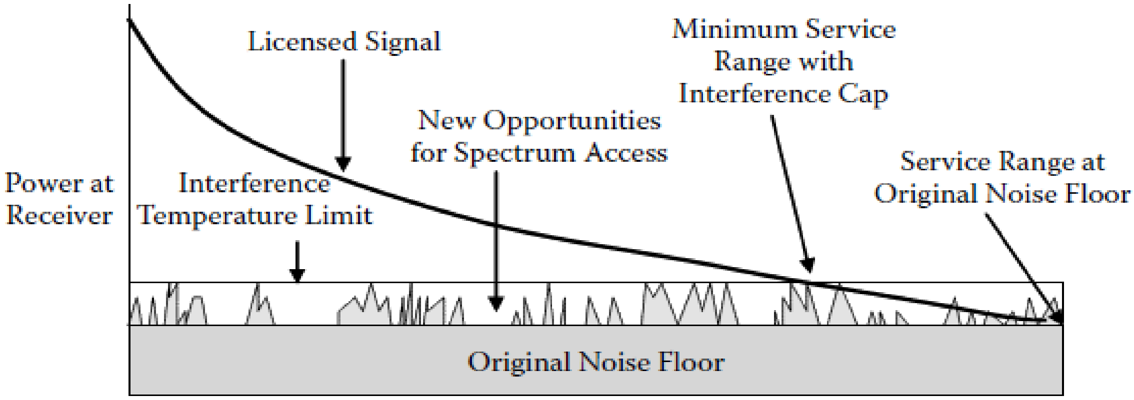


Fig. 2.9. Interference temperature Management

2.3 COOPERATIVE DETECTION

CR network can be optimized to exploit the available spectrum fully with greater sensitivity and efficiency if CR users within network share their information with each other.

2.3.A. DECENTRALIZED UNCOORDINATED TECHNIQUE

Each cognitive user in CR network scan independently to investigate presence of PU in given band and don't share the information with other CR user is known as decentralized uncoordinated detection technique. Uncoordinated technique is likely to more prone to false detection as compared to coordinated system. In this technique the chance of interference to PU is more by CR user because it is rely upon its decision only.

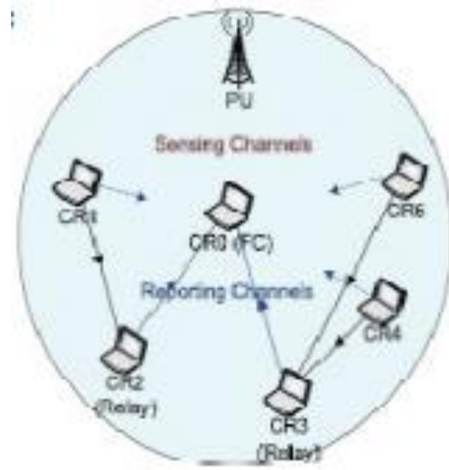


Fig.2.10.Decentralized Uncoordinated Detection Technique

2.3.B. CENTRALIZED COORDINATED TECHNIQUE

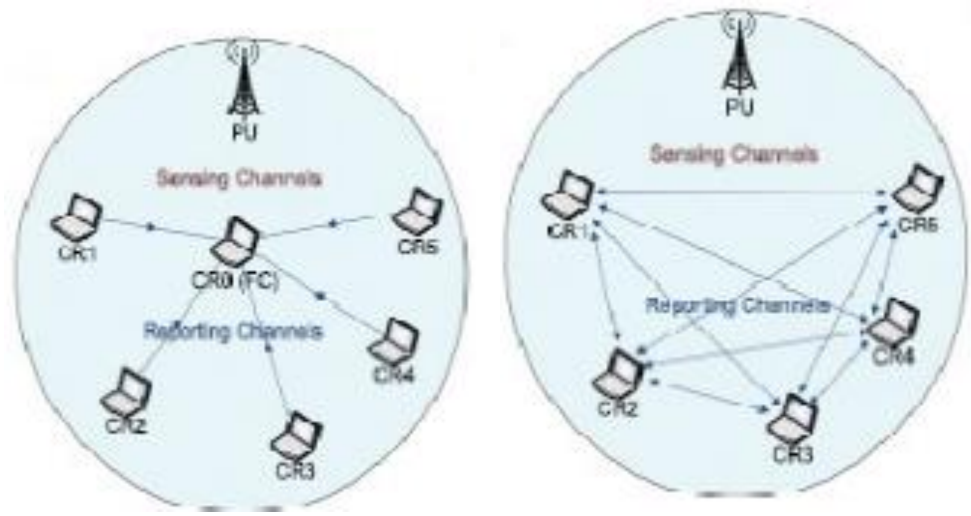
In these networks a well-organized infrastructure deployment is needed for the CR users. If one CR user senses the presence of a PU signal in given band, it sends information to a CR controller which can be another CR user or a wired immobile device. Then CR controller sends broadcast control message to all the CR users in its range. Centralized coordinated technique is further classified in following two categories based on their level of cooperation

Partially Cooperative

In this networks, CR users cooperate only in monitoring the channel. CR users detect the channel independently and inform the CR controller which then notifies all the CR users.

Totally Cooperative

In these schemes nodes cooperate in relaying each other’s information and also sense the channel cooperatively.



(A) (B)

Fig.2.11. (A) Centralized Coordinated Technique (B) Decentralized Coordinated Technique

2.3.C. DECENTRALIZED COORDINATED TECHNIQUE

There is no need of central CR controller in this type of coordinated CR network system. This type of network system works on clustering or gossiping algorithm where many nodes make a cluster combining all together for auto coordinating them. There is the need of a control channel for information broadcasting in clustered coordinated network which can be supplied by providing a dedicated frequency channel or transmitting broadcast message at low power.

Advantages and Disadvantages of Cooperative Detection

With the implementation of cooperation among CR users the need of sensitivity for sensing reduced substantially. Highly sensitive CR user needed to combat channel impairments like multipath fading, shadowing and building penetration losses which result into greater cost and power requirements. Cooperation among CR user reduces the sensitivity requirements up to -25 dBm.

The data overhead increased considerably. CR have to sense over wide band since it can use any spectrum hole now So CR user have to operate over large amount of data which makes it inefficient in terms of energy requirement, data throughput and delay.

CHAPTER 3

3. BLIND PARAMETER ESTIMATION OF THE SIGNAL

A signal possess certain properties like carrier frequency, symbol rate, modulation type, roll-off factor etc. after some operations in course of making it transmittable through media. Knowledge of these properties is desirable even sometimes essential while utilizing or recovering the signal. The properties of the received signal is known in many applications but sometimes it is desirable to utilize the signal from an unknown modulated source. Blind parameter estimation technique can be used to find the properties of received signal where the source is unknown. Blind parameter estimation is used for modulation classification and demodulation in non-cooperative spectrum sensing and software defined radio (SDR).

3.1. PRINCIPLE OF BLIND PARAMETER ESTIMATION

Usually in most of the communication applications like satellite communication etc. root raised cosine (RRC) pulses are used for baseband shaping of linearly modulated schemes viz. phase shift keying (PSK) and quadrature phase shift keying (QPSK). Among many parameters of RRC pulse shaped signal roll-off factor and symbol rate are most important characteristics. Roll-off factor defines the band width of a signal. If both the parameters, roll-off factor and symbol rate are estimated with greater accuracy, the problem of having prior information of transmitted signal for matched filter can be eliminated.

First stage of estimation is estimation of roll-off factor and coarse estimation of symbol rate. And main tool used for estimation at the first stage is Inverse Fourier Transform (IFFT). Later the coarse estimated symbol rate is refined by Least Square Estimation (LSE) method in second stage if the length of IFFT is short.

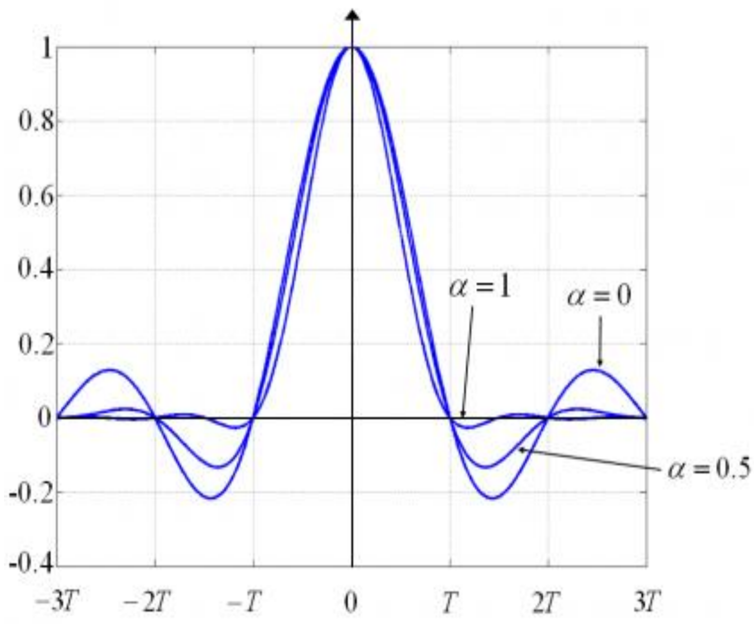


Fig.3.1. Root raised cosine pulse

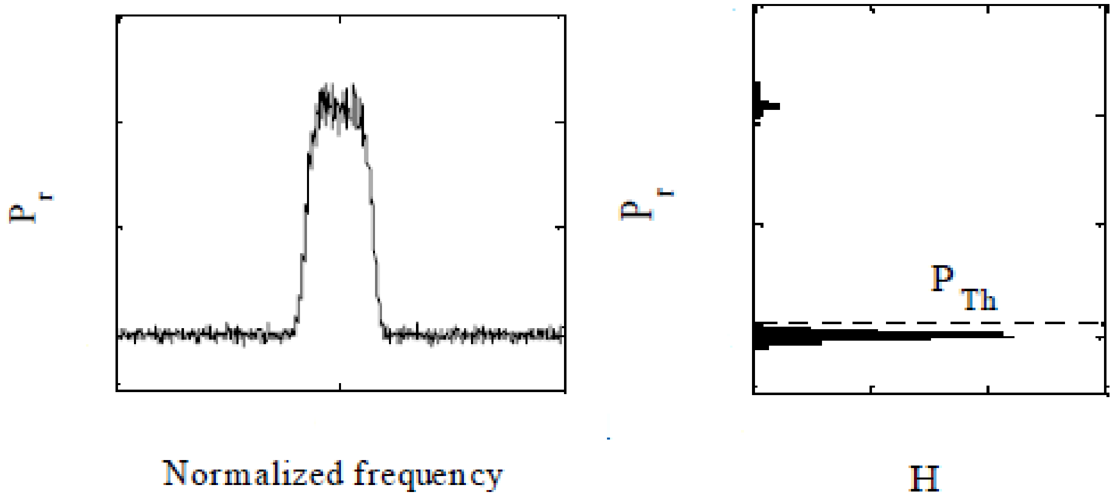
The equivalent RRC signal at the detector with amplitude A_p, time shift τ (less than or equal to half of the symbol period T), carrier frequency f_c and phase offset of θ is-

$$r_x(t) = A_p e^{j(2\pi f_c t+\theta)} \sum_k c_k h(t - kT - \tau) + w(t) \tag{3.1}$$

Where h(t) is RRC of unit energy Base Band Pulse with Roll of Factor α ($0 \leq \alpha \leq 1$). It is assumed that the independent and identically distributed M-ary symbols $c_k = a_k + jb_k$ have unit average energy. The Power Spectrum of the received signal-

$$P_r(f) = \frac{{A_p}^2}{2T} |H(f - f_c)|^2 + P_w(f) \tag{3.2}$$

Where H(f) is the Fourier Transform of baseband RRC Pulse h(t) and $P_w(f)$ is the power spectrum of AWGN component.



(A) (B)

Fig.3.2. (A) Power spectrum of received signal (B) Histogram plot of power spectrum

From equation (3.2) it is obvious that received signal is affected by noise. Direct IFFT operation over power spectrum will give much deviated values of the parameters being estimated from the real values of parameters. Therefore first preprocessing of the received signal is done before IFFT.

3.2. PREPROCESSING OF RECEIVED SIIGNAL

The power spectrum $P_r(f)$ of received signal is determined by averaging all the related periodograms Fig.3.2. (A). Since the power spectral density of white Gaussian noise is constant, Histogram method can be used to eliminate the effect of noise from the received signal. In the Histogram plot of received signal the longest bar which represent maximum frequency bins, is of AWGN because AWGN invariably present for all frequency. The maximum value of noise power can be found by observing Histogram and it is set as threshold P_{th}. Averaging all the value less than P_{th}, noise power P_w is calculated.

The noise free signal power spectrum can be estimated by

$$P_s(f) = P_r(f) - P_w \tag{3.3}$$

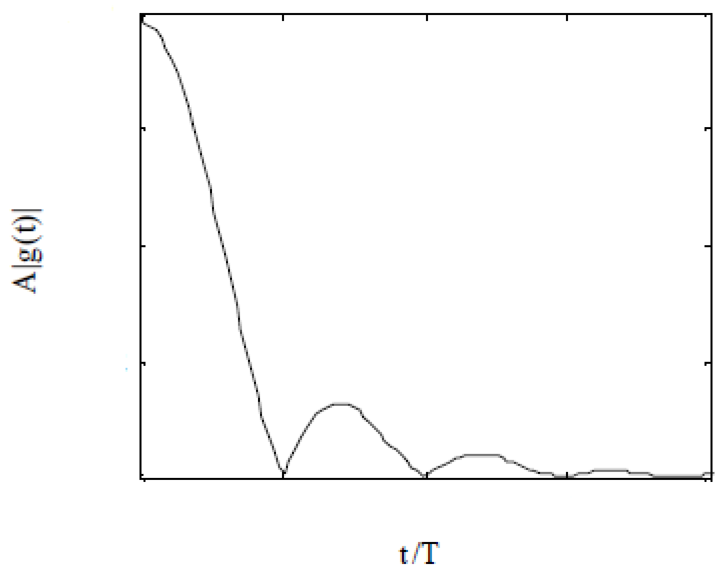


Fig.3.3. IFFT of preprocessed signal power spectrum

3.3. ESTIMATION OF COARSE SYMBOL RATE AND ROLL-OFF FACTOR

The IFFT of $P_s(f)$gives the magnitude of the RRC pulse, as shown in Figure 3.3. The modulus of IFFT gives A| $g(t)$|. The first minima of A| $g(t)$| gives coarse symbol rate.

. The RRC Pulse is given as-

$$g(t) = \frac{\sin(\pi t/T)}{\pi t/T} \frac{\cos(\pi \alpha t/T)}{1-4(\pi \alpha t/T)^2} \tag{3.4}$$

The RRC have its maximum value at t = 0. The ratio of minimum value ($g(t)_{min}$) to maximum value ($g(0)$) of RRC pulse is obtained for entire range of roll-off factor i.e. [0,1].

Which can be written as-

$$R = \frac{g(t)_{min}}{g(0)} \tag{3.5}$$

The Value of R for different values of roll-off factor α can be found out from the plot given below.

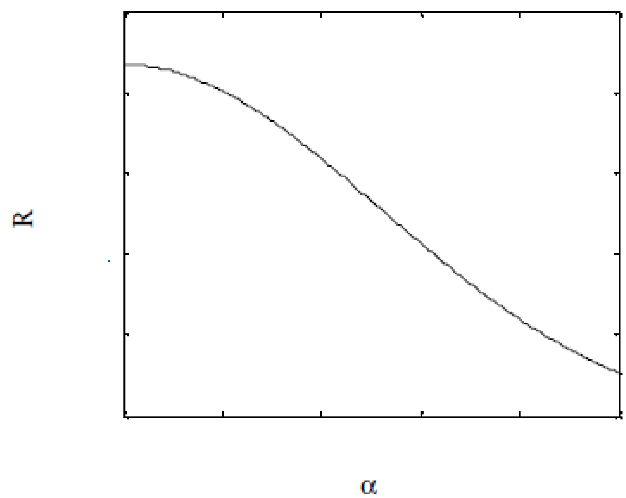


Fig.3.4. Plot of R Vs α

The IFFT of the pre-processed signal is shown in Fig.3.3. From the IFFT, the ratio of Second maximum peak to maximum Peak is computed and compared with $R(\alpha)$ to find the estimated roll-off factor.

3.4. REFINEMENT OF COARSE SYMBOL RATE

Second and final stage of parameter estimation is refinement of coarse symbol rate. With the estimated roll-off Factor $\hat{\alpha}$ and coarse estimated symbol rate $1/\widehat{T_1}$ we can construct a theoretical RRC pulse H($\widehat{T_1}$). LSE method is used for refinement of coarse symbol rate.

Said method rely its principle on reducing the difference of symbol period between theoretical signal $\mathrm{H}(\widehat{T_1})$ and observed data $g(t)$. The refined symbol rate is obtained by maximizing $J(T)$.

Where $J(T)$–

$$J(T) = g(t)^T \mathrm{H}(\widehat{T_1}) \left(\mathrm{H}(\widehat{T_1})^T \mathrm{H}(\widehat{T_1}) \right)^{-1} \mathrm{H}(\widehat{T_1})^T g(t) \tag{3.6}$$

Maximum value of $J(T)$ is searched in the range of the $[\widehat{T_1} - \Delta T, \widehat{T_1} + \Delta T\ ]$ where $\Delta T < \widehat{T_1}$. If maximum value of $J(T)$ is obtained in the m^{th} iteration the time resolution Δt will be $\Delta T / 2^{m-1}$. Utilising Δt refined symbol rate $1/\widehat{T_2}$ can be estimated.

CHAPTER 4

4. BLIND PARAMETER ESTIMATION BASED MATCHED FILTER DETECTION

The requirement of priori information of PU signal for MF detection can be eliminated by proposed technique. At the MF detector front end blind estimation of PU signal parameters is performed and coefficient of MF transfer function updated accordingly. Blind Estimation of signal parameters solves the problem of having priori information about PU signal for MF detector. Performance analysis and comparison of ED, conventional MF detector and proposed MF detector also have been done in this paper which show that the proposed MF detector perform better than ED and almost same as the conventional MF detector.

4.1 BLOCK DIAGRAM OF CONVENTIONAL MF DETECTION AND PROPOSED MF DETECTION TECHNIQUE

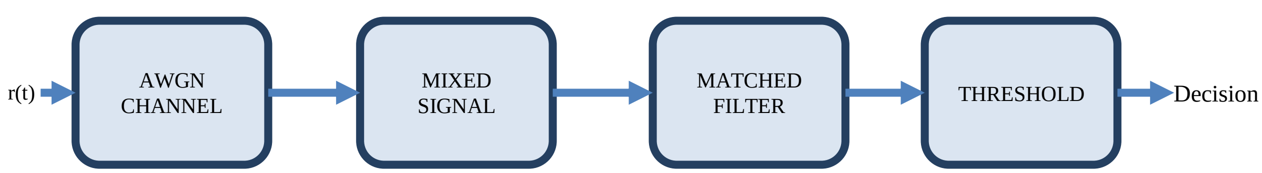


Fig. 4.1 Conventional MF detection

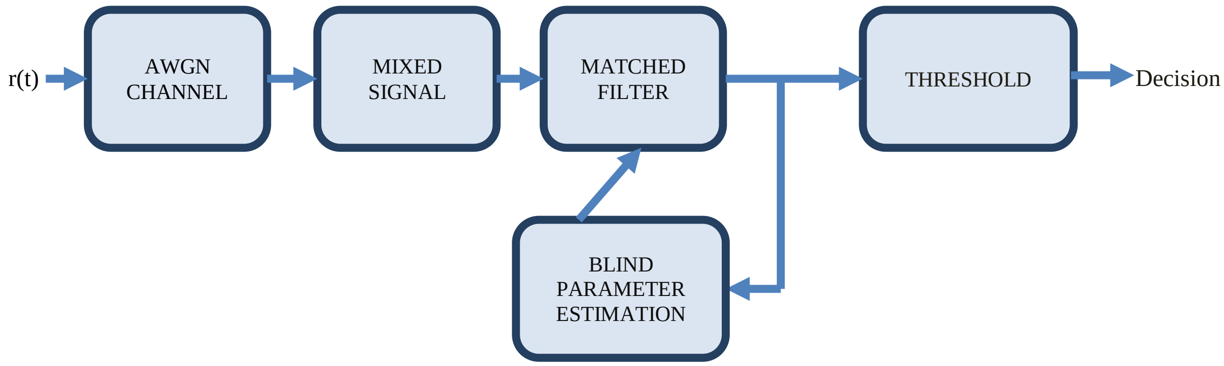


Fig. 4.2 Proposed MF detection

Block diagram of both detection scheme suggests that the PU signal arrives at detector as mixed signal which is the combination of PU signal and noise. And if the PU signal is not present in that particular channel then the mixed signal will be only noise. In conventional MF detection technique the PU signal is known to the MF. The MF correlates the mixed signal with known PU signal and compare the result with predetermined threshold and decision is taken. While in the block diagram of proposed MF detection scheme an extra blind parameter estimation block is added. Since the laterscheme does not require any information about PU signal, blind parameter estimation block keep estimating the PU signal and update the MF coefficients accordingly at the other hand it also track and compensate the effect of the variation of channel. After estimating the MF coefficients the result of correlation between mixed signal and MF coefficients is compared to a predetermined threshold and decision of occupancy of channel is taken same as conventional detection scheme.

4.2 WORKING AND FORMULATION OF PROPOSED DETECTION SCHEME

In CR the detection of PU signal existence is made on the basis of binary hypothesis test model which is well described in chapter 2. In our experiment we make the assumption that the additive noise w[n] encountered by PU signal is independent and identically distributed (iid) random Gaussian process with expectation E[|w(n)|]=0 and variance E[$|w[n]|^2$] = ${\sigma_w}^2$. And we also assume that the PU Signal p[n] is independent of noise w[n].

Based upon this assumption the binary hypothesis test model of decision for occupancy of channel being investigated is given as

$$r_x[n] = \begin{cases} w[n] & ; H0\ Hypothesis \\ p[n] + w[n] & ; H1\ Hypothesis \end{cases} \tag{4.1}$$

Where $r_x[n]$ is received signal, $H0$ is null hypothesis that signifies no PU signal but noise ispresent at detector. $H1$ is alternative hypothesis which depicts the presence of noise affected PU signal at the detector. The detector evaluate the decision statistic or test statistic by correlating the received signal with coefficients of MF carried out by known signal in case of conventional MF detection and correlate the received signal with coefficients of MF carried out by estimated signal in case of proposed MF detection. The PU signal detector has to choose between the two hypotheses on the basis of comparison between decision statistic and predetermined threshold. The decision statistic is given as,

$$D_E(r_x) = \sum_{n=0}^{M-1} |r_x[n]\widehat{r_x}[n]| \tag{4.2}$$

The decision statistic $D_E(r_x)$ under H0 hypothesis can be considered as a random variable with the PDF (probability density function)$P_o(D)$ which is a Chi-Square distribution with

M degrees of freedom for real case and 2M degrees of freedom for complex case. The binary hypothesis for deciding occupancy of channel can be modelled with test statistic and determined threshold as

$$\widehat{r_x} = \begin{cases} H0 & ;\ D(r_x) \leq \Upsilon \\ H1 & ;\ D(r_x) \geq \Upsilon \end{cases} \tag{4.3}$$

Where Υ is predefined noise dependent threshold which depend on received signal power and noise power

Application of MF at the receiver front end maximizes the SNR in case of PU signal is present due to convolution of received signal with transfer function of MF carried out by estimated signal. The coefficients of MF are complex conjugate of reversed signal. In MF operation the correlation of known signal p[n] with MF coefficients can be viewed as filtering operation. If h[n] is the impulse response of the MF, output of the MF can be given as-

$$Y_{MF}[n] = \sum_{k=0}^{M=1} h[n-k] r_x[n] \tag{4.4}$$

h[n] is the complex conjugate flipped around version of the PU signal given as

$$h[n] = {p_s}^*[M-1-n] \tag{4.5}$$

From (7) and (8) output of the MF can be given as

$$y_{MF}[M-1] = \sum_{n=0}^{M-1} r_x[n] {p_s}^*[n] = {r_x}^T p_s \tag{4.6}$$

The decision statistic of MF as shown in [13] is given as,

$$D_{MF}(r_x) = \left| \sqrt{\frac{2}{M \varepsilon_r {\sigma_w}^2}} \sum_{n=0}^{M-1} r_x[n] {p_s}^*[n] \right|^2 \tag{4.7}$$

Now the binary hypothesis test model can be given as-

$$r_x = \begin{cases} H0 & D_{MF} \leq \Upsilon \\ H1 & D_{MF} \geq \Upsilon \end{cases} \tag{4.8}$$

Where threshold value Υ is given by-

$$\Upsilon = \frac{\varepsilon_r}{\sigma_w{}^2} \tag{4.9}$$

False Alarm for the MF detection will be when H1 is decided while H0 hypothesis is true. In this case the received signal $r_x[n]$ at detector front will be noise w[n]. Therefore the output of MF from (9) can be written as-

$$y_{MF}[M-1] = \sum_{n=0}^{M-1} \mathrm{w}[n] p_s{}^*[n] \tag{4.10}$$

Probability of false alarm for MF detection is given as

$$P_{fa,MF} = P(D_{MF} > \Upsilon | H0) \tag{4.11}$$

$$P_{fa,MF} = Q\left(\frac{\Upsilon}{\sqrt{\varepsilon_r \sigma_w{}^2}}\right) \tag{4.12}$$

Probability of detection of PU signal is deciding H1 when H1 hypothesis true. In this case received signal $r_x[n]$ will be $p[n] + w[n]$ and the output MF-

$$y_{MF}[M-1] = \sum_{n=0}^{M-1} \big[p[n] + w[n]\big] p_s{}^*[n] \tag{4.13}$$

The probability of detection for MF is given as

$$P_{D,MF} = P(D_{MF} > \Upsilon | H1)$$

$$P_{D,MF} = Q\left(\frac{\Upsilon - \varepsilon_r}{\sqrt{\varepsilon_r \sigma_w{}^2}}\right) = Q\left(\frac{\Upsilon}{\sqrt{\varepsilon_r \sigma_w{}^2}} - \sqrt{\frac{\varepsilon_r}{\sigma_w{}^2}}\right)$$

$$= Q\left(Q^{-1}\big(P_{fa,MF}\big) - \sqrt{\frac{\varepsilon_r}{\sigma_w{}^2}}\right) \tag{4.14}$$

Probability of miss detection is deciding H0 while H1 hypothesis is true and is given as-

$$P_{md,MF} = P(D_{MF} < \Upsilon | H1) = 1 - P_{d,MF} \tag{4.15}$$

4.3 PROPOSED DETECTION APPROCH WITH BLIND ESTIMATION OF SIGNAL PARAMETER

Here we consider fact that Root Raised Cosine (RRC) Pulse is normally used for baseband shaping in Linear Digital Communication. In the proposed scheme we are trying to estimate the signal parameter so that in MF detection we can get rid of the problem of having priori knowledge of PU signal. Roll of Factor is an important characteristic of the signal which decides the shape of transmitted symbol. Theperformance of our proposed detection technique lie upon the accuracy of the estimation of roll off factor and symbol rate. In next subsection we present the signal model, roll off factor and symbol rate estimation technique used in our approach.

4.3. A SIGNAL MODEL

We assume the independent and identically distributed M-ary symbols $c_k = a_k + jb_k$ with unit average energy is being transmitted. The equivalent RRC signal at the detector with amplitudeA_p, time shift τ (less than or equal to half of the symbol period T), carrier frequency f_c and phase offset of θ is-

$$r_x(t) = A_p e^{j(2\pi f_c t+\theta)} \sum_k c_k h(t - kT - \tau) + w(t) \tag{4.16}$$

Where h(t) is RRC of unit energy Base Band Pulse with Roll of Factor α ($0 \leq \alpha \leq 1$). The Power Spectrum of the received signal-

$$P_r(f) = \frac{{A_p}^2}{2T} |H(f - f_c)|^2 + P_w(f) \tag{4.17}$$

Where H(f) is the Fourier Transform of baseband RRC Pulse h(t) and $P_w(f)$ is the power spectrum of AWGN component.One reliable and easy way to eliminate the noise power P_w from the received signal Power Spectrum $P_r(f)$ is histogram method.

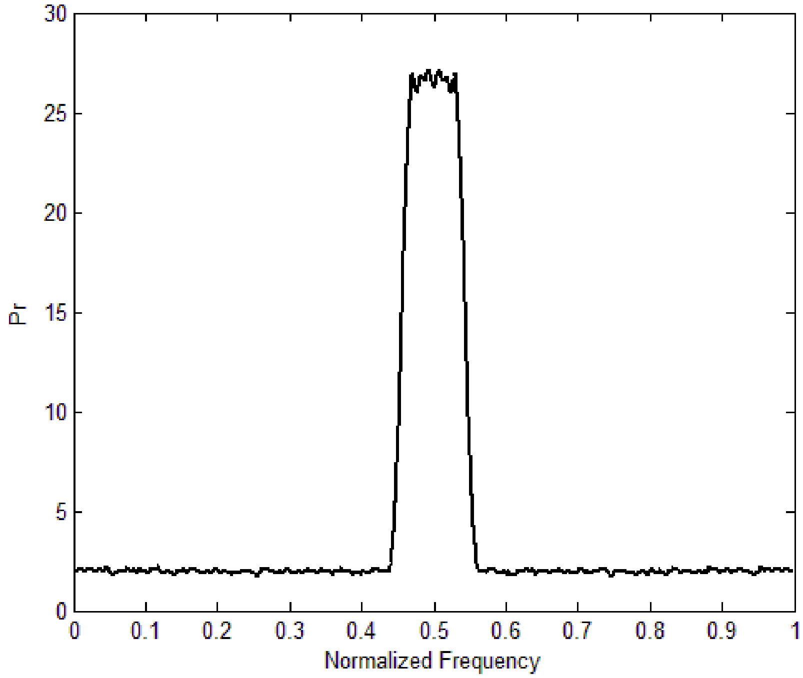


Fig.4.3. Power Spectrum of received signal

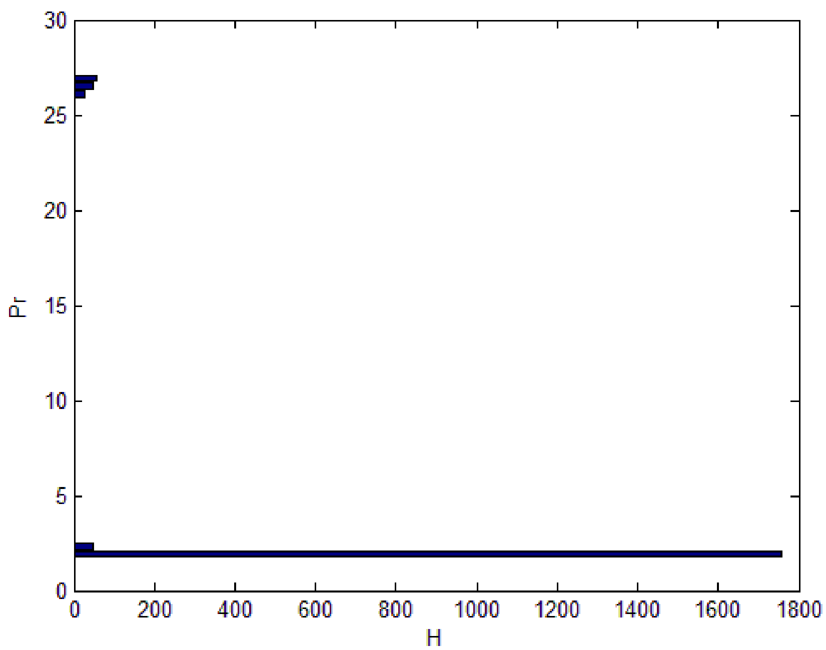


Fig.4.4 Histogram of received signal Power Spectrum

By scrutinizing the histogram of power spectrum$P_r(f)$, we can find the maximum value of noise power. Noise is considered AWGN here which will affect all frequency components therefore in AWGN Power $P_w$will seize maximum number of bins and have the largest bar in histogram. By averaging all the samples below maximum value of noise power we can obtain the noise power P_w in the received signal power spectrum$P_r(f)$. The estimated PU signal power spectrum will be $P_{\hat{p}}(f) = P_r(f)$ - P_w.

4.3. B ROLL-OFF FACTOR AND SYMBOL RATE ESTIMATION

The RRC Pulse is given as-

$$g(t) = \frac{\sin(\pi t/T)}{\pi t/T} \frac{\cos(\pi\alpha t/T)}{1-4(\pi\alpha t/T)^2} \tag{4.18}$$

RRC Pulse has maximum value at t = 0 i.e. $g(0)$. Now we can find out the value of $g(t)_{min}/g(0)$ for different value ofα where $g(t)_{min}$ is minimum value of $g(t)$. Given ratio can be written as a function of α –

$$R(\alpha) = \frac{g(t)_{min}}{g(0)} \tag{4.19}$$

The IFFT of the pre-processed signal $P_{\hat{p}}(f)$ is A$|g(t)|$ as shown in fig.(3). From the IFFT A$|\, g(t)|$ we can compute the value of the Second Maximum Peak / Maximum Peak. Comparing this value with $R(\alpha)$ we can estimate the Roll of Factor $\hat{\alpha}$. The first minima of $P_{\hat{g}}(f)$ IFFT i.e. A$|\, g(t)|$ gives the coarse estimation of Symbol Rate$1/\widehat{T}_1$. If the IFFT length is very large, coarse estimation of symbol rate will be sufficient alone to deliver accurate estimation of symbol rate. If length is not large, resolution has to be increased by zero padding and suitable interpolation and LSE is performed to get refined symbol rate $1/\widehat{T}_2$.

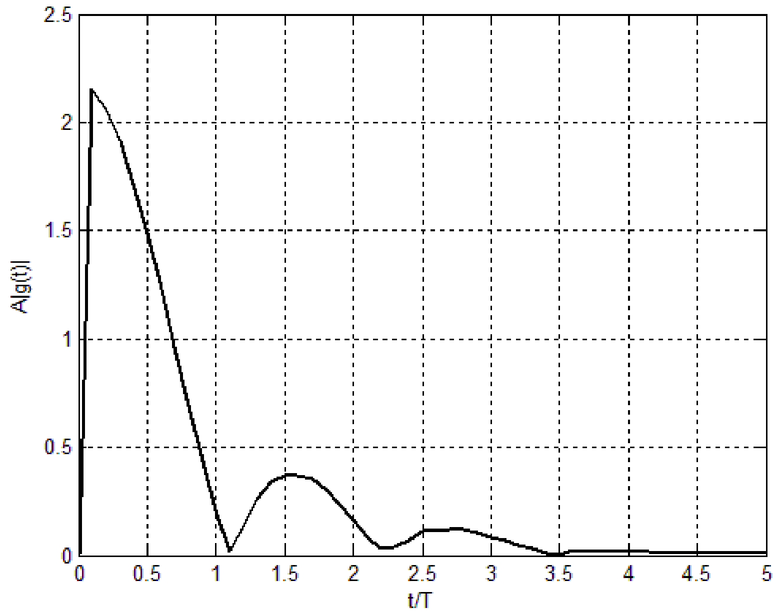


Fig.4.5. IIFT of pre-processed received Signal Power Spectrum

From the estimated value of Roll of Factor $\hat{\alpha}$ and coarse estimated symbol rate $1/\widehat{T}_1$ we can construct a theoretical signal $\mathrm{H}(\widehat{T}_1)$. Now LSE is used to reduce the difference of symbol period between theoretical signal $\mathrm{H}(\widehat{T}_1)$ and observed data $g(t)$. The LSE is obtained by maximizing $J(T)$ [13]. Where $J(T)$–

$$J(T) = g(t)^T \mathrm{H}(\widehat{T}_1)\left(\mathrm{H}(\widehat{T}_1)^T \mathrm{H}(\widehat{T}_1)\right)^{-1} \mathrm{H}(\widehat{T}_1)^T g(t) \qquad (4.20)$$

Maximum value of $J(T)$ searched in the range of the $[\widehat{T}_1 - \Delta T, \widehat{T}_1 + \Delta T\ ]$ where $\Delta T < \widehat{T}_1$. If maximum value of $J(T)$ is obtained in the m^{th} iteration the time resolution Δt will be $\Delta T/2^{m-1}$. Utilising Δt refined symbol rate $1/\widehat{T}_2$ can be estimated. With the estimated value of Roll of Factor $\hat{\alpha}$ and symbol rate $1/\widehat{T}_2$, the PU signal $\hat{p}(t)$ can be estimated and coefficient of MF detector can be modified according to (10). Thus our proposed detection scheme solves the problem of having priori information about PU signal for MF detection.

4.4 SIMULATION RESULTS AND DISCUSSSION

4.4.A SIMULATION SETUP

Considering the fact that in digital communication usually root raised cosine (RRC) pulse signals are used as base band signal for transmission, we carried out our experiment with equiprobable random bpsk data which was transmitted after pulse shaping by RRC pulse shaping filter as PU signal. The roll-off factor was kept 0.4 of transmitted RRC Baseband signal and signal was transmitted with 1KHz symbol rate. The signal was transmitted through additive Gaussian channels and related periodograms were averaged to estimate and eliminate the noise by histogram method. The estimated roll-off factor of received signal, estimated by blind signal parameter was found 0.38 instead of 0.4 while the coarse symbol period estimated was 1.1 ms instead of 1 ms. 1000 Monte-Carlo Simulation was performed to get probability of detection. IFFT length of 2048 was taken to find A$|g(t)|$so no further need of refinement of symbol rate. Probability of detection P_d and probability of miss detection P_{md} with probability of false alarm was calculated for -5 dB SNR. While probability of detection with SNR was calculated for 0.01 probability of false alarm.

4.4.B PERFORMANCE EVALUATION

Fig.4.6. shows the performance of ED, Conventional MF detector and proposed MF detector with probability of false alarm at -5 dB SNR. At such low SNR ED performance is worst among the three discussed techniques.

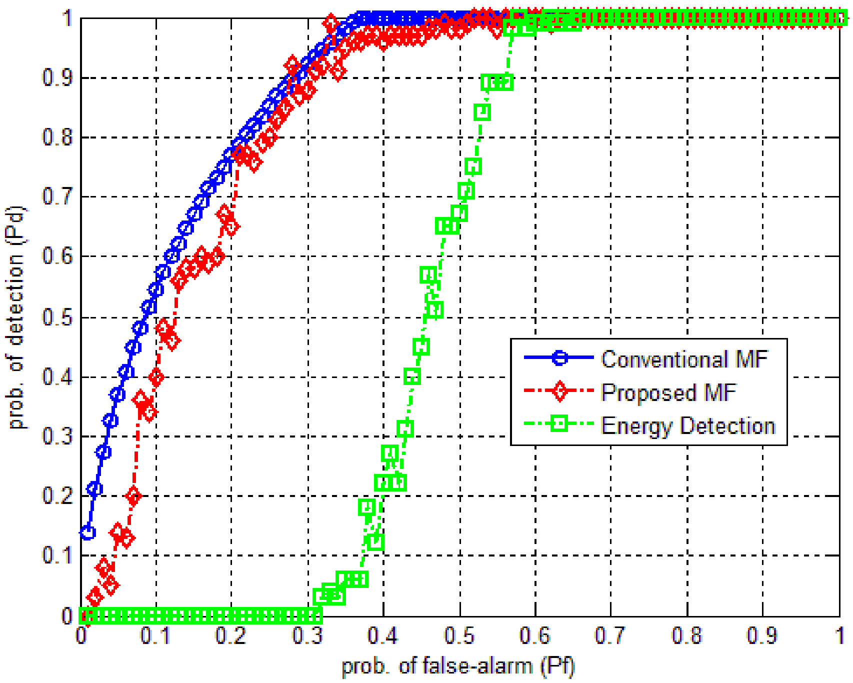


Fig.4.6. Probability of Detection response with Probability of False Alarm for ED, Conventional MF and Proposed MF Detection at -5 dB SNR

Up to 0.3 permissible probability of false alarm (P_{fa}) the probability of detection of ED is almost zero while the proposed detection technique have the probability of detection of 0.9. It is also obvious from the Fig.4.6 that proposed technique's probability of detection graph increases steeply right from zero with probability of false alarm whereas conventional MF does not respond till 0.3 probability of false alarm. At 0.4 value of permissible P_{fa} the proposed detection technique attains maximum possible value of P_d i.e. 1 while ED technique acquire 20% P_d for the same value P_{fa} and acquire 100% P_d with about 60% P_{fa}. So simulated figure suggests that proposed detection scheme performs far better than ED technique and close to conventional MF detector. Fig.4.7. compares the chances of miss detection with various values of probability of false alarm for proposed MF detection, conventionalMF and ED technique. Figure shows that with ED technique chances of miss detection is 100% up to 30% permissible P_{fa} while the proposed technique have only about 10% chances of miss detection at same value of P_{fa} which is very close to the performance of conventional MF detection technique. With 35% of P_{fa}, the probability of miss detection (P_{md}) is almost zero while for ED technique for same value of P_{fa}, the P_{md} is 90%. So from performance graph it can be concluded that chances of miss detection in proposed detection scheme is very less than ED and almost same as conventional MF detector. Fig.4.8. is the performance evident of all the three discussed techniques with SNR. It is clear from the figure that all the three detection techniques perform equally well at higher

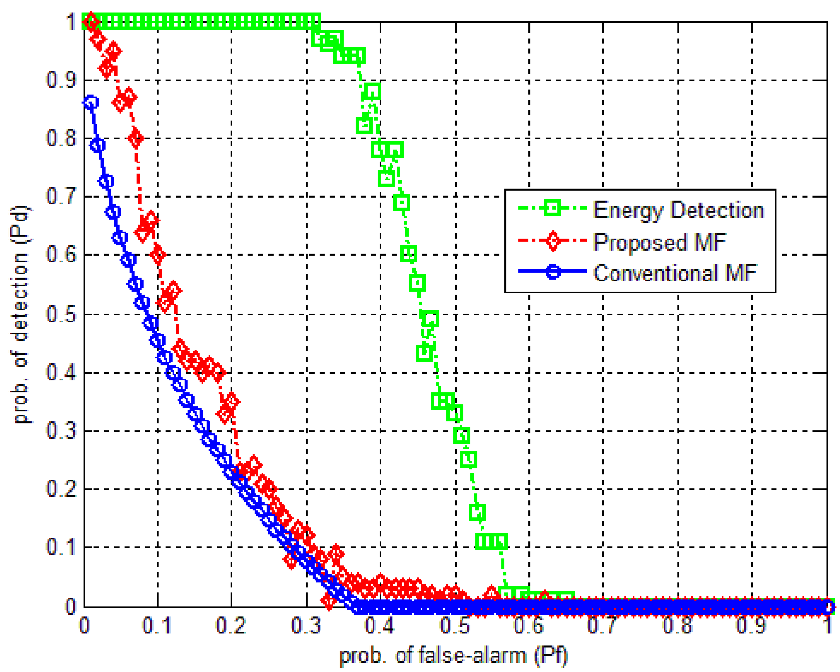


Fig.4.7. Probability of Miss Detection response with Probability of False Alarm for ED, Conventional MF and Proposed MF Detection at -5 dB SNR

SNR. But at lower SNR proposed MF detector perform better than ED and almost same as conventional MF detector.At about -5.8 SNR the probability of detection for proposed technique is 0.08 while for ED technique the P_d is almost zero.

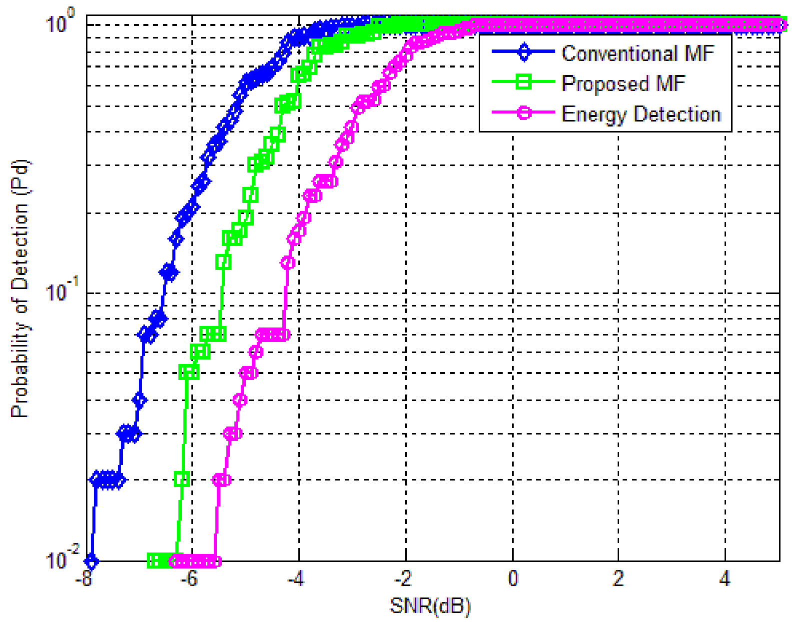


Fig.4.8. Probability of Detection response with SNR for ED, Conventional MF and Proposed MF Detection at 0.01 P_{fa}

CHAPTER 5

5. CONCLUSION

Sensing of Spectrum holes should be rapid and precise to avoid the delay and interference to PU. Detection technique also should be sensitive enough to avoid missing of any available spectrum hole. Among the most used detection technique, ED technique is used vastly due to its simple implementation and universal application for all type of signal irrespective of modulation used. But the problem with this technique are its poor performance at low SNR, prone to noise uncertainty, not able to differentiate between spread coded signals and noise. These disadvantages limits ED application to few areas where accuracy and sensitivity doesn't matter more. CS detection technique is a robust and reliable sensing technique which can work at low SNR. But it is not so popular due to its complex implementation and long operational time. MF is an optimal detection technique in AWGN environment even at low SNR provided CR user should have prior information about PU signal. Requirement of prior information is the main problem of MF detection because a dedicated MF have to be installed for each type of signal therefore this technique is not so popular for spectrum sensing in wideband.

The problem of having prior information of PU signal in conventional MF detection is solved by our proposed technique "Blind Parameter Estimation Based Matched Filter Detection". Here CR user estimates the PU signal parameter and update the MF coefficients accordingly thus need of prior information is eliminated. This proposed detection technique performs far better than ED technique and comparable to the performance of conventional MF at low SNR as obvious by simulation results. Detection performance of proposed technique is also comparable to conventional MF detection.

5.1 FUTURE SCOPE

The proposed method is a well potent technique which can replace other two popular techniques, ED technique and CS technique respectively. But a lot of research work still needed for making it operational in wide band scenario.

- The technique can be made adaptive to work under variable environment for fast decision.
- Still the performance of proposed technique to be tested under fading, shadowing and multipath reflection.
- Up to now proposed detection technique is applied for narrow band detection under AWGN channel. The research can be further extended to check the applicability of proposed MF detector in wideband.

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